LANSCE
Los Alamos Neutron Science Center

Research Proposal for the use of Neutron Science Facilities

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Date Received: 03/09/11

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Days Recommended: 0
Dates Desired:
Impossible Dates: 7/24-8/1/2011

TITLE
Neutron Capture Spin Distributions and Validation of Surrogate Reaction Technique: Continuation

☒ Continuation of Proposal #: S1318
☐ Ph.D Thesis for:

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RESEARCH AREA

- ☐ Biological and Life Science
- ☐ Chemistry
- ☐ National Security
- ☐ Earth Sciences
- ☐ Engineering
- ☐ Environmental Sciences
- ☒ Nuc. Physics/chemistry
- ☒ Astrophysics
- ☐ Few Body Physics
- ☐ Fund. Physics
- ☐ Elec. Device Testing
- ☐ Dosimetry/Med/Bio
- ☐ Earth/Space Sciences
- ☐ Materials Properties/Test
- ☐ Other:
- ☐ Mat'l Science (incl Cond Matter)
- ☐ Medical Applications
- ☐ Nuclear Physics
- ☐ Polymers
- ☐ Physics (Excl Condensed Matter)
- ☐ Instrument Development
- ☒ Neutron Physics
- ☐ Fission
- ☒ Reactions
- ☒ Spectroscopy
- ☐ Nuc. Accel. Reactor Eng.
- ☒ Def. Science/Weapons Physics
- ☐ Radiography
- ☐ Threat Reduction/Homeland Sec.
- ☐ Other:

FUNDING AGENCY

- ☐ DOE/BES
- ☐ DOE/OBER
- ☒ DOE/NNSA
- ☐ DOE/NE
- ☐ DOE/SC
- ☐ DOE/Other
- ☐ DOD
- ☒ NSF
- ☐ Industry
- ☐ NASA
- ☐ NIH
- ☐ Foreign:
- ☐ Other US Gov't:
- ☐ Other:

PUBLICATIONS

Publications:

NONE

Abstract: S1519_95mo-cizew-c.pdf

By electronic submission, the Principal Investigator certifies that this information is correct to the best of their knowledge.

Safety and Feasibility Review*(to be completed by LANSCE Instrument Scientist/Responsible)*

☐ **No further safety review required** ☐ **To be reviewed by Experiment Safety Committee**

☐ **Approved by Experiment Safety Committee,Date:**

Recommended # of days:	**Change PAC Subcommittee and/or Focus Area to:**	**Change Instrument to:**

Comments for PAC to consider:

Instrument scientist signature: **Date:**

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Neutron Capture Spin Distributions and Validation of Surrogate Reaction Technique: Continuation

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Scientific context

Neutron capture cross sections on unstable nuclei are important quantities for understanding the synthesis of the heavy elements in stars and applications in nuclear energy and nuclear forensics. It is extremely difficult to measure directly (n,γ) cross sections on nuclei with $t_{1/2}$<100 days because of the intense background from gamma radiation from the decay of the target, even when samples are small. Therefore, it is important to develop a surrogate method for (n,γ), develop the techniques to measure surrogate reactions on very short-lived nuclei, especially those more than 1-2 units from stability, and validate this indirect approach. The Facility for Rare Isotope Beams (FRIB) will be capable of measuring surrogates for neutron-induced reactions on short lived nuclei, should such an approach be validated. There is a sizeable research community interested in using FRIB for such studies [Lis09].

The (d,pγ) reaction is a candidate for a surrogate method to determine (n,γ) reaction cross sections on unstable nuclei. In addition, the (d,pγ) reaction is a promising candidate for an inverse kinematics surrogate with rare isotope beams. With beams of ≈5 MeV/A impinging on ≈200 $\mu g/cm^2$ CD_2 targets, the reaction protons are detected preferentially at back angles in the laboratory, well separated from strong elastic scattering on the target materials [Pai07]. Ground state Q-values for this reaction are usually positive, which means lower beam energies, which are also possible using hydrogenous (rather than heavier element) targets. While neutron capture dominates at low ℓ values (s and p waves), charged particle reactions are expected to bring in more angular momentum. Therefore, understanding the differences in the spin distributions as a function of neutron energy between (n,γ) and a surrogate reaction has been identified as a key component in deducing (n,γ) cross sections from surrogate reactions [Esc10,Sci10]. The spin distributions can be determined by measuring the γ-ray de-excitation of the yrast levels (lowest 2^+, 4^+, 6^+, etc. states). From recent calculations by Kawano and Jandel [Kaw11], the positive-parity excitations are expected to dominate the decay of the compound nucleus.

Pathway to validation of (d,pγ) as a surrogate for (n,γ)

The present proposal is part of a coordinated effort to validate (d,pγ) as a surrogate reaction for (n,γ). The project goals are:

- Measure gamma-ray cascades in (n,γ) and relate the observed decay to the spin distribution of the decaying compound nucleus;
- Measure decay of the compound nucleus and deduce spin distributions in (d,pγ) in both normal and inverse kinematics;
- Provide constraints on theoretical models of spin distributions for (d,pγ) reactions;

- Develop a prescription to deduce (n,γ) cross sections from (d,pγ) surrogate measurements that takes into account the differences in spin distributions;
- Compare (n,γ) cross sections as a function of neutron energy deduced from the surrogate reaction to those from direct measurements.

The choice of target for this project required one for which neutron capture cross sections had been measured up to at least 200 keV; ^{95}Mo(n,γ) has been measured as displayed in Fig. 1 [Mus76]. To facilitate the analysis, the final nucleus should be even-even, where the $2^+ \rightarrow 0^+$ transition collects almost all of the decay of the compound nucleus. To validate (d,pγ) as a surrogate for (n,γ) will require modeling of the spin distributions, and subsequent decay, of the compound nucleus. In order to reduce the sensitivity of the theoretical analysis to details of nuclear structure, a nucleus somewhat removed from shell closures is preferred [For07, Esc10, Esc10a]. The November 2010 LANL workshop on surrogate reactions endorsed ^{95}Mo as the best target for validation of the surrogate reaction.

The ^{95}Mo(d,pγ) surrogate measurement in inverse kinematics has been approved to run at HRIBF and is waiting to be scheduled with a setup that builds on previous measurements [Ciz07,Pet09]. The ^{95}Mo(d,pγ) surrogate measurement in normal kinematics is approved to run at LBNL with the STARS-LIBERACE system [Bur06] of charged particle and gamma-ray detectors developed by the LLNL-LBNL collaboration; it should be completed by mid-2011. Jutta Escher and colleagues [Esc10] have developed tools to infer information on spin distributions from gamma-ray cascades, which will make it possible to deduce (n,γ) cross sections from surrogate cross sections. The missing critical piece is the measurement of the ^{95}Mo(n,γ) spin distributions as a function of neutron energy.

A preliminary measurement of the ^{95}Mo(n,γ) reaction was made in September 2010 on FP12 at the Lujan Center at LANSCE. As described below, we feel that we have determined the optimal experimental set up to maximize the success of completing this measurement.

Preliminary results from the September 2010 FP12 ^{95}Mo(n,γ) reaction study

The ^{95}Mo(n,γ) reaction was measured with a stack of four enriched (96.8%) ^{95}Mo foils with a total areal density of ≈24 mg/cm^2. Two HPGe detectors were used at 3 unique distances from the target. The original proposal had assumed 2-3 detectors in a close-packed geometry. From the preliminary analysis, we conclude that the detectors need to be about 12 inches from the target, to obtain the best peak-to-background yield in the γ-ray spectrum of ^{96}Mo, especially at higher neutron energies. An example of the γ-ray data is displayed in Figs. 2 and 3 when the detector was ≈12 inches from the target. Although most of the ^{96}Mo γ-ray data come from capture on the 44.9 eV resonance, the $2^+ \rightarrow 0^+$ transition of interest can also be discerned in the spectrum corresponding to higher energy neutron capture.

The data acquisition for these measurements included a 12-bit waveform digitizer. The online algorithm used preset leading and trailing edges of the waveforms to determine the amplitude and width of individual waveforms that translate to energy and width of individual γ rays. The digitizer was initially set to save the waveforms of γ rays that come from one out of every 100 beam pulses. The γ-ray signals from the decay of the compound nucleus ^{96}Mo for neutron energies $E_n > 10$ keV reach the detectors at time $t < 35\mu s$. During this time, the digitizer has yet to recover from processing the signal from the γ flash. Therefore, almost all of the events from higher energy neutrons were not processed. We did not appreciate until the last few days of the beam time that all waveforms needed to be recorded for subsequent offline analysis to extract the γ-ray spectra. (When full waveforms are recorded, 4GB of data are recorded in about 15 minutes, making each run very short). The offline algorithm developed by John O'Donnell uses the second derivative of the waveforms to determine the amplitude and width of the waveforms. This technique accurately separates two or more overlapping waveforms. The impact of the offline second derivative algorithm is displayed in Figure 4. The offline analysis provides the expected shape for the neutron energy spectrum. In contrast the spectrum from the on-line analysis has an unphysical shape, because events at short times were lost.

The main problem with the September 2010 experiment was the need to record all waveforms for subsequent off line analysis. In addition, there were also several data acquisition computer crashes (total loss of more than 1 day) and the gains for both Ge detectors shifted every few hours throughout the run. To maximize count rate, we also tried three unique detector configurations. It was only in the offline analysis that we fully appreciated that closer-packed detector configurations have poor peak-to-background ratios, and that the initial detector configuration, 12 inches from the target, was optimal.

Beam time request.
We are requesting 17 days of beam time to complete the measurement of the ^{95}Mo(n,γ) reaction at FP12 at the Lujan Center. The new run will benefit from what we learned from the September 2010 measurement. We will run with a significantly thicker (60 mg/cm^2) ^{95}Mo target. We will work to identify a third HPGe detector for the experiment. We will optimize the shielding of the Ge detectors, from scattered neutrons and background γ rays. Full waveforms will be recorded with the digital data acquisition system, for subsequent offline analysis. Rutgers postdoc Aderemi Adekola will be the lead person in all aspects of the measurement.

The neutron flux on FP12 has been measured to be about a factor of 2 higher than in our original proposal. Therefore the extrapolated neutron flux at 100 keV is 2.7 n/s/cm^2/eV. Using 0.01% efficiency for the HPGe γ-ray detector array 12 inches from the target, a 50% neutron energy bin, and a cross section of 0.18 barns at 100 keV, we estimate over 1000 counts in the $2^+ \rightarrow 0^+$ transition in ^{96}Mo with a 60-mg enriched ^{95}Mo target and 17 days of beam time. The intensity of the $4^+ \rightarrow 2^+$ transition could be reduced by 20-40%, depending upon the actual spin distribution [Esc10, Sci10].

In summary, we request 17 days of beam time on FP12 to complete the measurement of ^{95}Mo(n,γ) spin distributions as a function of neutron energy up to E_n=200 keV. We will also need a week of access to FP12 to setup the apparatus, unless we follow an experiment with a very similar setup.

References

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[Sci10] N.D. Scielzo et al., Phys. Rev. C **81**, 034608 (2010).

Figures:

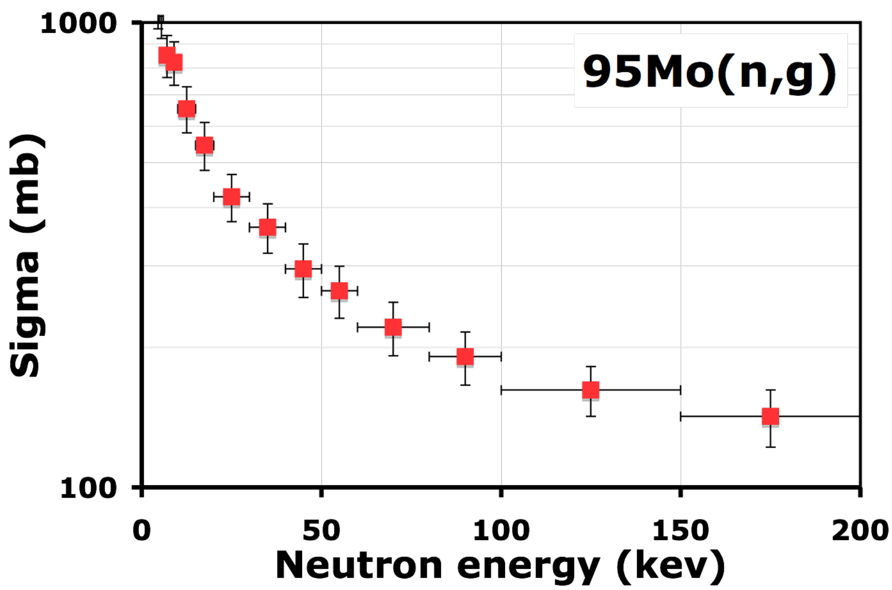

Figure 1. Measured ^{95}Mo(n,γ) cross sections as a function of neutron energy in keV [Mus76].

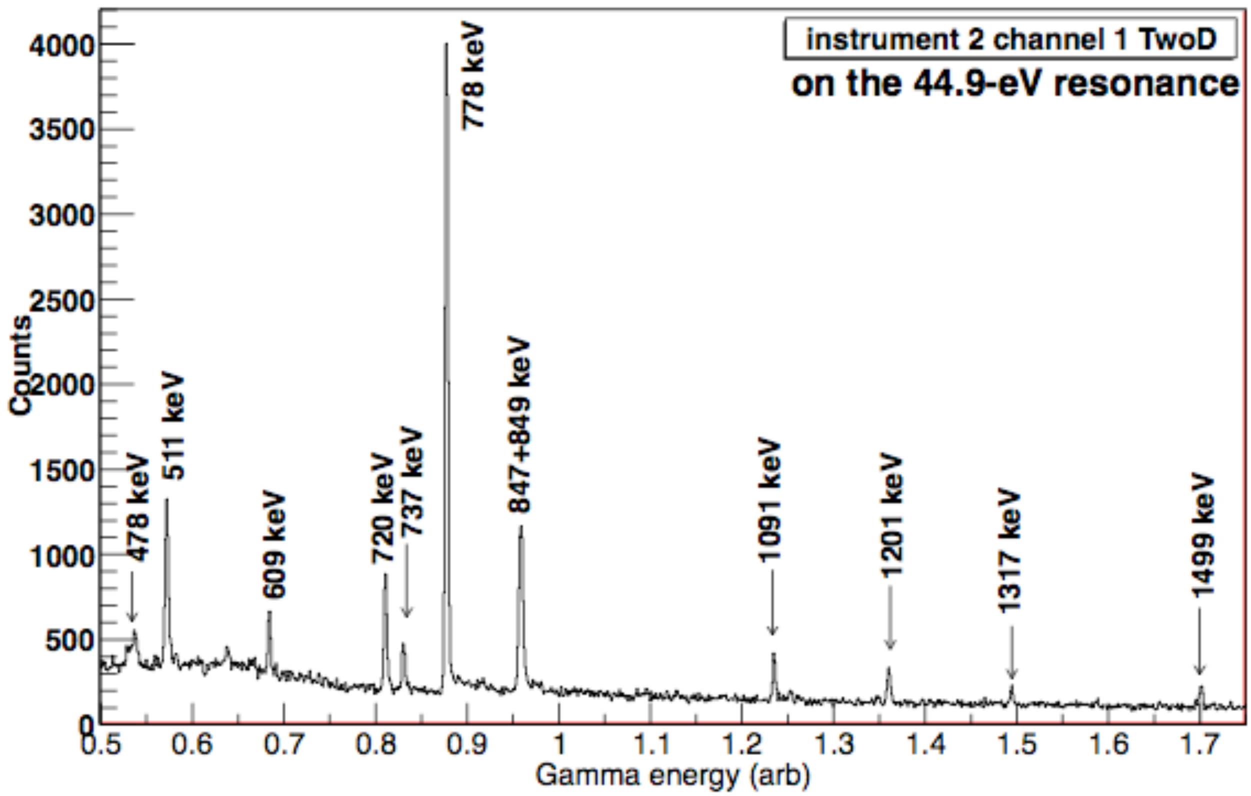

Figure 2. Preliminary ^{95}Mo(n,γ) gamma-ray spectrum on the 44.9-eV resonance taken with detector 1 ≈12 inches from the target; 16 hours of data. The $2^+ \rightarrow 0^+$ transition in ^{96}Mo is at 778 keV. All of the strong peaks above the 511-keV line are in ^{96}Mo, including the $4^+ \rightarrow 2^+$ transition at 849 keV.

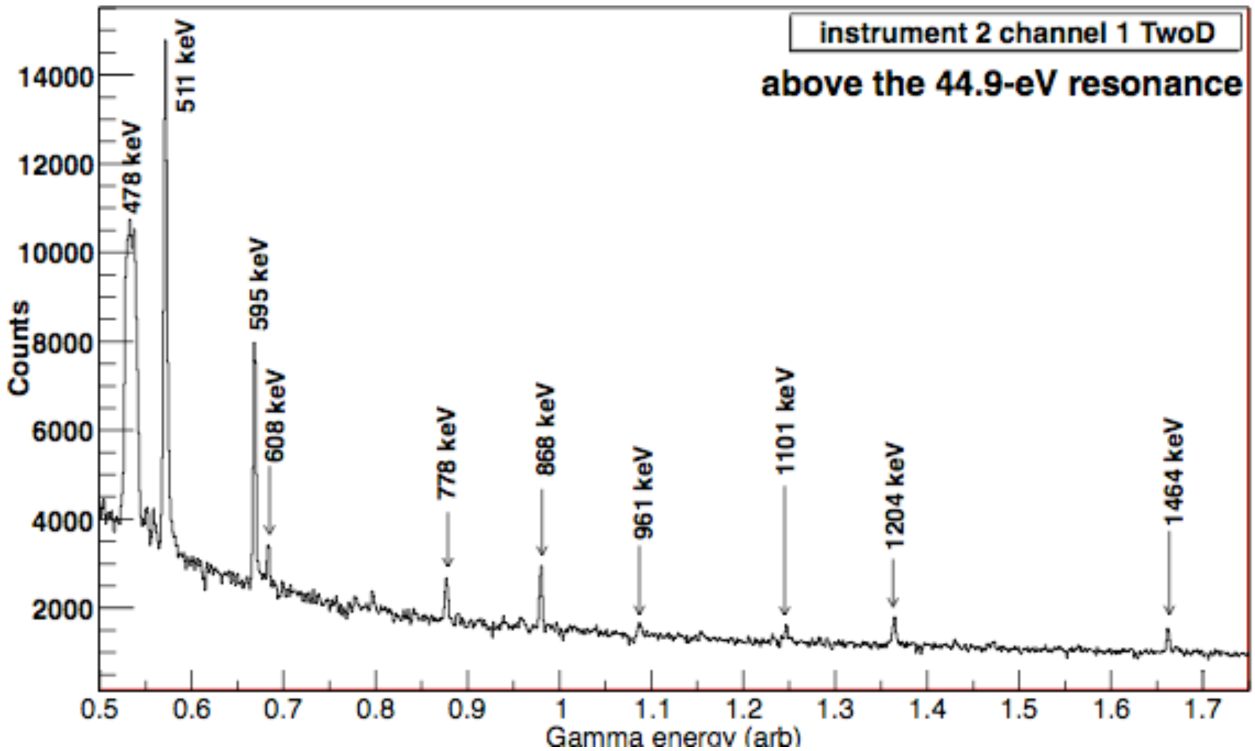

Figure 3. Preliminary gamma-ray spectrum for neutron energies > 45.2 eV taken with detector 1 ≈12 inches from the target. The $2^+ \rightarrow 0^+$ transition in ^{96}Mo is at 778 keV. All of the other strong lines above 511 keV are from (n,γ) reactions with the Ge (predominantly ^{73}Ge) in the detector.

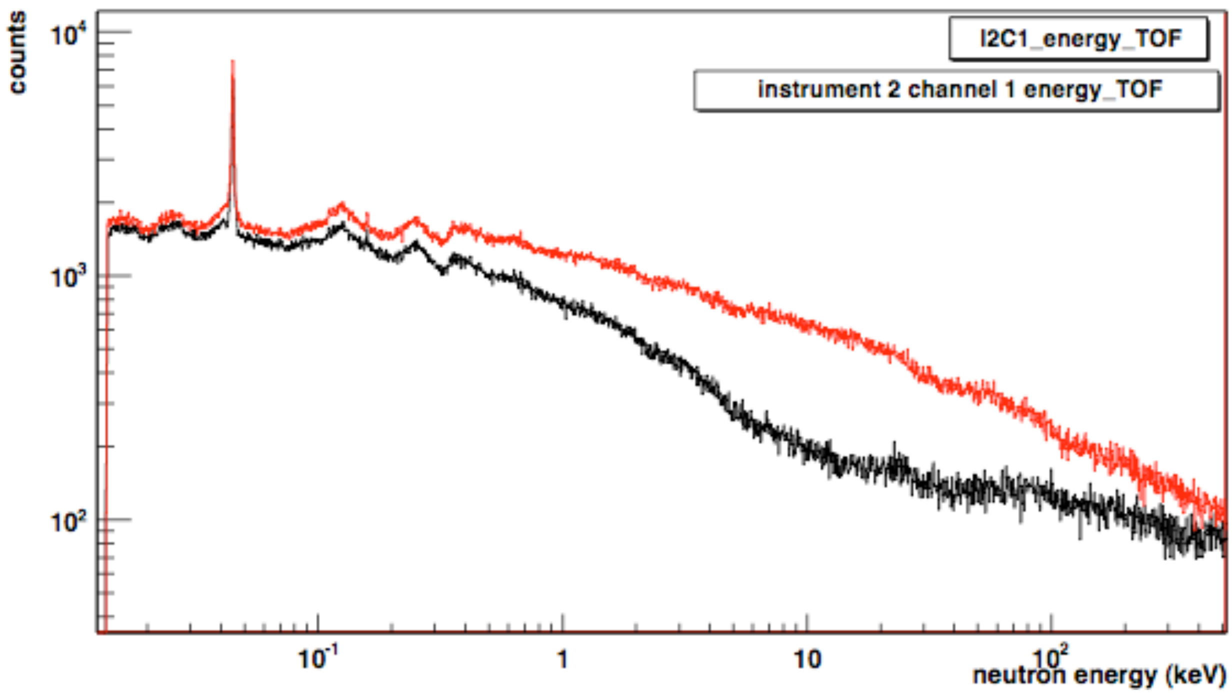

Figure 4. ^{95}Mo neutron energy spectrum from online (black, bottom) and offline (red, top) analysis.